Brain Booster to Go?

By Gail Kay Haines

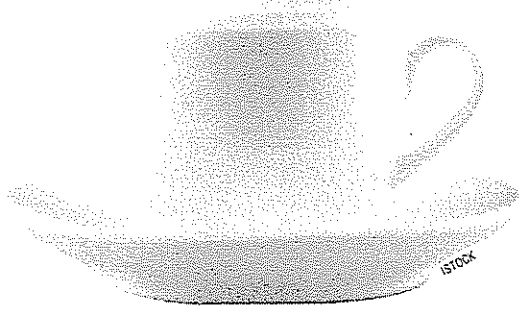
The first buzzer sounds in seven minutes, and you are still in line at Starbucks. Classmates streak across the street, backpacks flapping and cardboard cups in hand. You already have one tardy this quarter, so maybe you'd better forgo that triple shot mocha grande. But there is a test in chemistry, second period, and you need the boost to get your brain moving. Decisions, decisions.

A hot trend in senior and junior high schools around the country is coffee-shop coffee—the fancier the better. Sometimes, it is not even hot. Coffee-and-crushed-ice concoctions are especially popular. Sugar, whipped cream, pile it on! Chains or local favorites—even a coffee bar in the school lunchroom—offer upscale coffee.

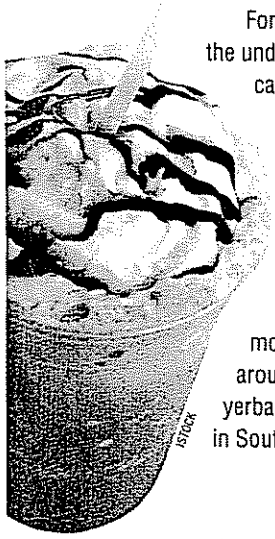
High-calorie extras aside, a cup of coffee is hot water pushed through a scoop of roasted and powdered beans. More than 800 different chemicals go into that famous aroma, making coffee brown and rich, bitter and sweet, stimulating and soothing. When it comes to coffee, it's all in the chemistry.

But will it help you ace your chemistry exam? And is it worth the price—to your nervous system, as well as your wallet?

Let's sift the evidence.



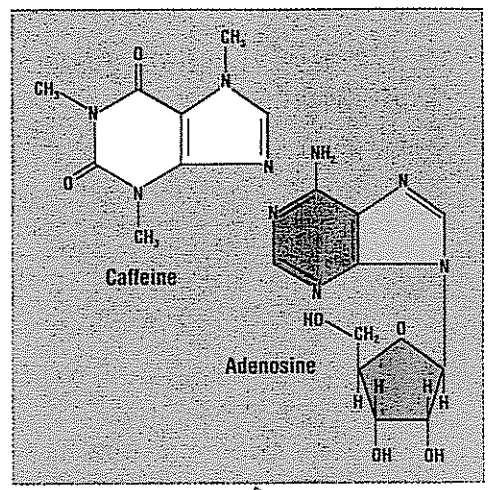
How coffee works in the brain

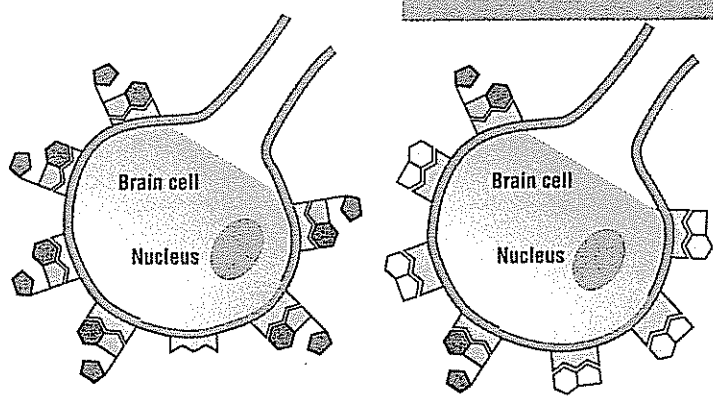


For most coffee drinkers, the underlying allure of coffee is caffeine, the most widely consumed mind-altering chemical in the world. "Caffeine" is the common name for 1,3,7-trimethylxanthine ($C_8H_{10}N_4O_2$), a bitter white powder found in more than 60 kinds of plants around the world, including tea, yerba mate (a popular beverage in South America), and kola nuts.

A brain chemical called adenosine regulates drowsiness. When you are tired, adenosine builds up inside your brain and attaches to proteins on brain cells called adenosine receptors, causing drowsiness. As you drink coffee, molecules of caffeine get inside the brain and bind to these adenosine receptors (Fig. 1), but unlike adenosine, caffeine excites brain cells.

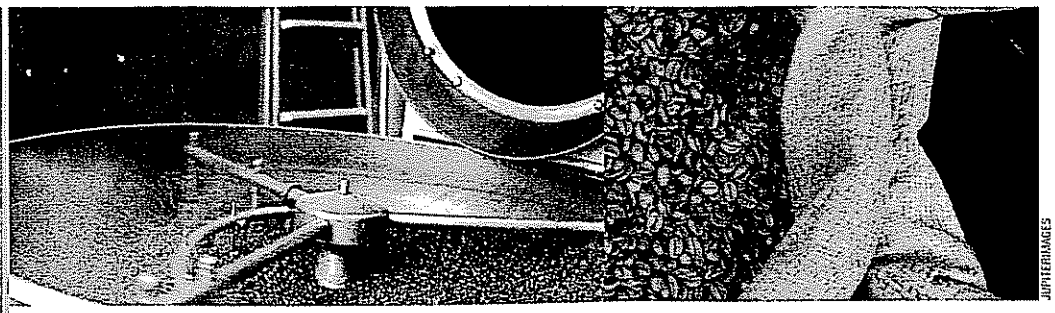
If caffeine blocks enough receptors, you can stay awake for hours, after which the caffeine molecules are broken down and eliminated. Usually, caffeine is effective 15 minutes to 1 hour after your last latte, and the peak lasts about 3 to 3 1/2 hours.





a. Brain cell without caffeine. b. Brain cell with caffeine.

Figure 1. Caffeine and adenosine molecules have similar shapes, so they can both bind to proteins on brain cells called adenosine receptors. When you feel sleepy (a), adenosine molecules bind to most of these receptors, but when you drink coffee (b), some caffeine molecules attach to these same receptors, making you alert instead of sleepy.



Chemicals in coffee

Scientists have identified more than 800 chemicals in coffee beans, including caffeine, sucrose, and cellulose. Others include proteins and acids such as citric acid, which is found in acidic fruits; tartaric acid, the main acid in wine; and formic acid, the stinging poison secreted by ants.

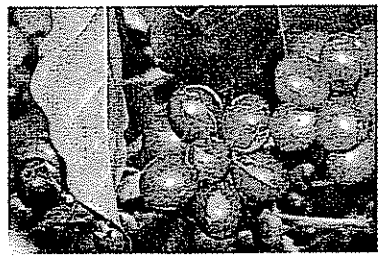
When coffee is roasted, chemical reactions inside the beans destroy some molecules and create new ones. There are different degrees of roasting. Some people prefer lightly roasted coffee—roasted barely a few minutes—while others like it better when the beans have roasted for half an hour. In each case, the chemical composition of the coffee is different.

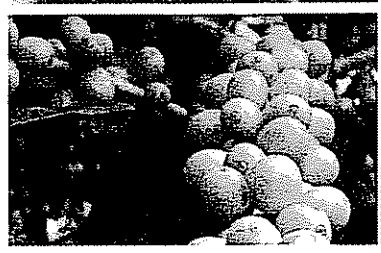
As coffee beans absorb heat (at temperatures between 188 °C and 282 °C), their color shifts from green to yellow to light brown, and then to dark brown. Oils make their surface shiny. Chemical reactions inside the beans turn carbohydrates and fats into aromatic oils, burn off moisture and carbon dioxide, and alternately break down and build up acids, unlocking the characteristic coffee flavor.

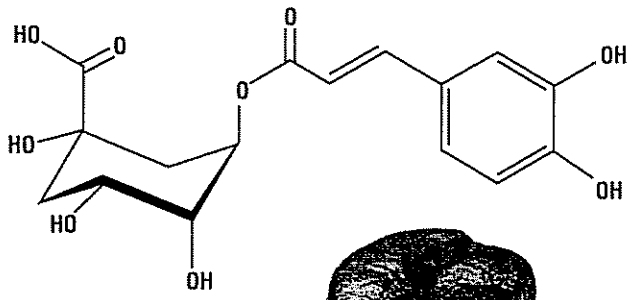
Robert Benck, roastery manager at Batdorf and Bronson Coffee Roasters, Olympia, Wash., started working with coffee while in college. "Both my chemistry and Spanish classes have been useful in my career," he says as he stands in a warehouse filled with *Coffea arabica* beans from places like Mexico, Guatemala, and Costa Rica.

Benck explains that as coffee beans roast, they first pop due to pressure inside and then swell and split. A chemical process, called the Maillard reaction, combines heated sugar and amino acids present in the beans to form hundreds of color and flavor molecules.

After about 12 minutes, a second pop can be heard, and the beans start oozing out oils. At both pops, and for several days after, roasted coffee beans give off carbon dioxide—so much that if coffee bags are sealed too quickly, they can burst.







Example of a chlorogenic acid

Coffee is not only about caffeine

An important family of chemicals present in coffee is called chlorogenic acids. Scientists are discovering that chlorogenic acids may provide health benefits beyond caffeine's effects. These molecules make up between 6% and 12% of the chemicals present in green coffee beans, while caffeine is only 1% to 2% of the total.

Chlorogenic acids belong to a group of chemicals called antioxidants, which protect cells against damage from free radical molecules formed inside cells. Free radicals can damage DNA and have been associated with Alzheimer's disease, cardiovascular disease, cancer, and diabetes.

"Coffee is the number one source of antioxidants in the U.S. diet," says Joe Vinson, professor of chemistry at the University of Scranton, Pa. "Chlorogenic acids—primarily from coffee—are probably the major single antioxidant found in the diet."

Peter Martin, a professor of psychiatry and pharmacology at Vanderbilt University, Nashville, Tenn., and Adriana Farah, a chemistry professor at the Universidade Federal do Rio de Janeiro, Brazil, have studied chlorogenic acids and their antioxidant derivatives formed through chemical reactions in roasting coffee beans. They have concluded that light- to medium-roast coffees contain the most of these antioxidants.

"It is hard to know exactly the health effects of these various compounds since they act together," Martin says. "It's as if you were putting together a jigsaw puzzle, and you are studying one piece of the puzzle—that is, each chemical in coffee—at a time."

At Pavia University, Italy, Gabriella Gazzani and colleagues found that green coffee's antioxidant properties are mainly due to chlorogenic acids. Even though chlorogenic acids are degraded up to 70% when coffee beans are roasted, the more roasted the coffee is, the more it contains antioxidants called melanoidins, which are created through the Maillard reaction.

Chlorogenic acids are either absorbed by the stomach and the intestines or broken down into other compounds that are also antioxidants. Vinson and colleagues have shown that chlorogenic acids slow the release of glucose into the bloodstream after a meal, thus lowering blood sugar levels. Other studies show that they reduce the risk of hypertension and type 2 diabetes. Chlorogenic acids also may have other health properties, still being investigated.

Potential benefits against alcoholism and stress-related disorders

Martin and colleagues have made chlorogenic acid derivatives in their laboratory and studied their properties on the brain cells of rats. They have found that these chemicals bind to proteins on the surface of brain cells that also bind to drugs that reduce alcohol craving. These results show that consuming coffee may help people suffering from alcoholism.

Another team of scientists led by Yoshinori Masuo, a researcher at the National Institute of Advanced Industrial Science and Technology, Tsukuba, Japan, has shown that simply inhaling the aroma of roasted coffee may have beneficial health effects. When sleep-deprived rats sniff coffee, proteins in their brain cells are activated to protect them from stress-related damage. In other words, chemicals in coffee's aroma, alone, can relieve stress.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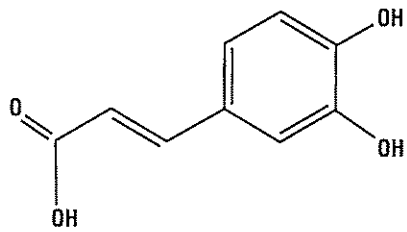
"These results may provide a new way of relieving stress and maybe of helping in the treatment of mental disorders related to stress, including depression, autism, and attention-deficit hyperactivity disorder," Masuo says.



Caffeic acid

Additional health benefits of coffee

Coffee may also protect teeth. Farah, Gazzani, and Beatriz Gloria, a chemistry professor at the Universidade Federal de Minas Gerais, Belo Horizonte, Brazil, have shown that chemicals in roasted—but not green—coffee inhibit the growth of bacteria that cause tooth decay.

The scientists found a variety of different antibacterial chemicals which killed or inhibited the growth of *Streptococcus mutans*, the major cause of dental decay in humans. Also, Gazzani and colleagues applied roasted coffee to hydroxyapatite, a component of tooth enamel—the hard white substance covering a tooth—and showed that small molecules present in coffee prevented *S. mutans* bacteria from binding to it.

Coffee may also help kill bacteria that infect our guts and lungs. Gloria, Farah, and colleagues have shown that chlorogenic acids, trigonelline, caffeine, caffeic acid, and protocatechuic acid inhibit the growth of enterobacteria, which can cause food poisoning, diarrhea, and typhoid fever. The researchers suggest that these chemicals could be used in foods as a natural preservative to control bacterial growth.

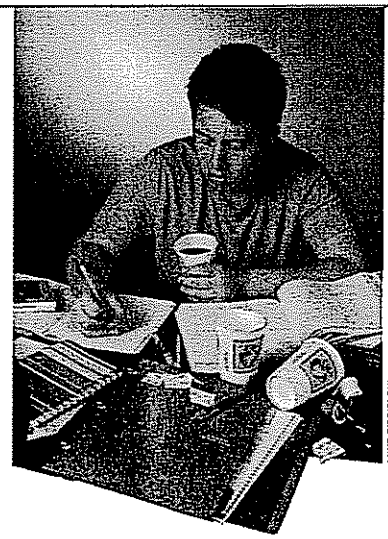
Surprisingly, caffeine and cholorogenic acids may have opposing effects in the brain. Martin and colleagues have found that chlorogenic acid derivatives stimulate adenosine molecules to bind to brain cells, thus acting contrary to caffeine. So, when you drink coffee, the effects of caffeine and chlorogenic acids on brain cells seem to balance out.

Another interesting finding was recently made by Gloria and her team. They discovered that coffee contains tryptophan, a chemical converted by the body into a brain chemical called serotonin that helps regulate sleep, appetite, and mood, and inhibits pain.

So is coffee good for you?

Back to that chemistry exam second period. The timing is right. Your caffeine level will be at its peak. And, as many studies have shown, the drink will improve your mood and increase your mental alertness, cognition, and reaction speed—even your ability to do simple math problems. So far, so good. Will it make you smarter? You wish! There is absolutely no evidence linking coffee with increased brain power—just alert use of your brain.

And is caffeine addictive? Do you risk becoming a "java junkie?" Yes and no. Brains get so used to caffeine's effects that a withdrawal headache can result. But most experts agree that caffeine is not as addictive as illegal drugs, such as heroin and cocaine, because too much caffeine just makes you jittery, and withdrawal symptoms are mild. Caffeine is on the Food and Drug Administration's list of food additives that are "generally recognized as safe."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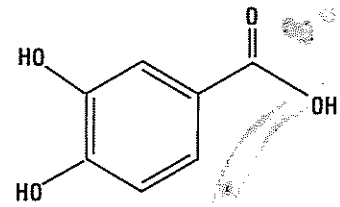
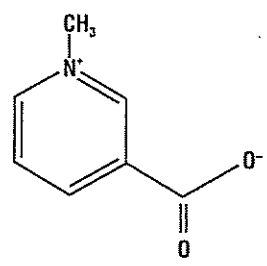


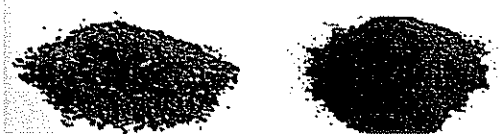
Protocatechuic acid

Here is the bottom line. If coffee works for you, that's great. But food experts suggest drinking no more than three cups of coffee per day. People who regularly consume more may find themselves restless, irritable, and sleepless. Also, some people have caffeine sensitivity. If just one small coffee gives you a red face and a pounding heart, stick to noncaffeinated beverages.

But if you enjoy a mocha in the morning or a latte with lunch, you have plenty of company. Coffee is experiencing a new renaissance, says the National Coffee Association, and it is enjoying yearly sales of more than $11 billion. Coffee is the most traded commodity next to oil and the world's most popular drink next to water.



Trigonelline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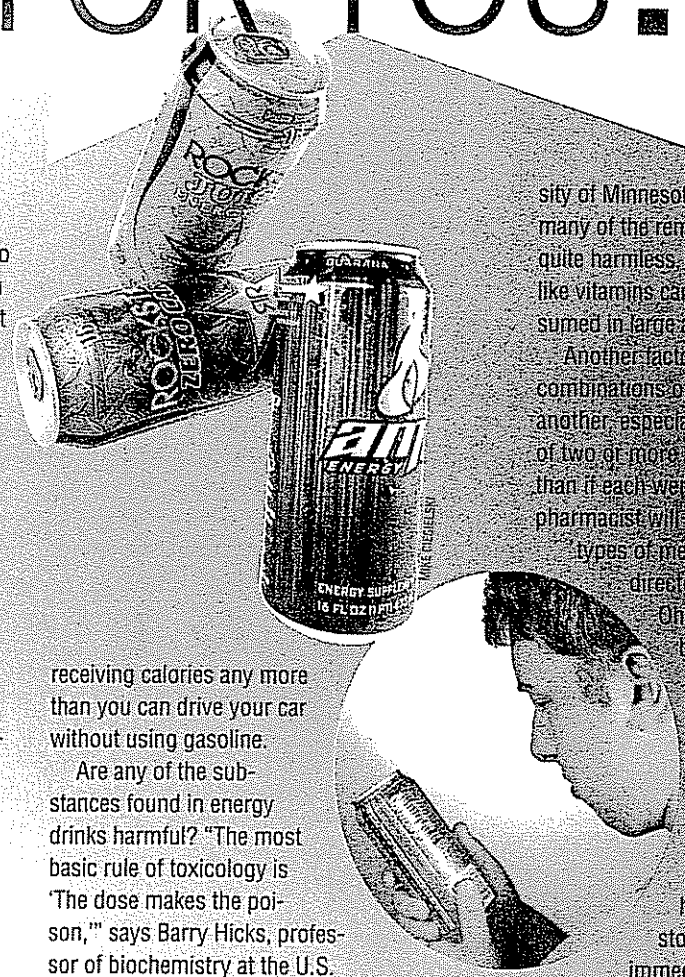
Gail Kay Haines is a science writer and book author from Olympia, Wash. Her most recent article, "Corn—The A"maiz"ing Grain," appeared in the December 2006 issue of *ChemMatters*.

ARE Energy Drinks Good FOR YOU?

By Brian Rohrig



You decide to pull an all-nighter to study for that big chemistry test tomorrow. So you chug an energy drink in the hopes it will provide that boost of energy you need to get you through the night. Energy drinks—not to be confused with sports drinks, which are specially formulated to replenish what the body loses during intense exercise—are the latest beverage fad.

Last year, U.S. sales alone topped the billion-dollar mark. At close to three dollars a can, it's not hard to see why! Energy drinks are packaged in brightly colored cans that appeal to the youth market. And for an added coolness factor, they even fluoresce brightly under a black light. The manufacturers claim the energy boost you receive will enhance athletic performance, improve your memory, and stimulate your metabolism.

But some critics suspect a dark side to these beverages. In mid-March, four middle school students in Broward County, Fla., were taken to the hospital via ambulance with their hearts racing and their bodies dripping with sweat after consuming energy drinks. Most energy drinks come with warnings on their labels, advising children, pregnant women, and those "sensitive to caffeine" not to drink them.

Do energy drinks give you energy? Absolutely. The amount of Calories in each can tell you how much energy it provides. (The word Calorie—with a capital C—actually refers to kilocalories.) There are only three food nutrients that can give you calories: fat, carbohydrate, and protein. The water, vitamins, and minerals found within energy drinks cannot provide any calories. Some additives—like caffeine—may appear to give you an energy boost, but you cannot release energy without receiving calories any more than you can drive your car without using gasoline.

Are any of the substances found in energy drinks harmful? "The most basic rule of toxicology is 'The dose makes the poison,'" says Barry Hicks, professor of biochemistry at the U.S. Air Force Academy, Colorado Springs, Colo. "Nearly every substance is harmful if consumed in large enough quantities in a short time."

Caffeine is by far the most potent substance in energy drinks. Because it is commonly consumed, it is viewed by many as innocuous. But since every energy drink packs a hefty dose of caffeine, people should consume them moderately and responsibly.

The large sugar content of energy drinks is also a cause for concern. "Energy drinks are basically soda pop on steroids—not literally, but figuratively!" says Ted Labuza, Morse Alumni Distinguished Teaching Professor of Food Science and Engineering at the University of Minnesota, Twin Cities. "Even though many of the remaining ingredients appear quite harmless, even beneficial substances like vitamins can be toxic to the body if consumed in large amounts."

Another factor to consider is how the combinations of substances affect one another, especially since the combined effects of two or more substances may be greater than if each were taken separately. "Any pharmacist will tell you not to mix certain types of medications," says Jackie Buell, director of sports nutrition at The Ohio State University, Columbus. "Since all of the energy drinks are relatively new to the market, their long-term effect on the body is not known."

If you consume energy drinks, Buell suggests to always read the label and heed any warnings and to stop drinking energy drinks immediately if you experience an elevated heartbeat, nausea, or any other unusual symptoms. ▲

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Brian Rohrig teaches at Jonathan Alder High School in Plain City (near Columbus), OH. His most recent *ChemMatters* article, "The Olympic Flame: Chemistry Held High," appeared in the October 2008 issue.

Common Chemicals Found in an Energy Drink

CAFFEINE (1,3,7-trimethylxanthine: $C_8H_{10}N_4O_2$): a brain stimulant that increases alertness and staves off sleep; works by binding to brain cells in the same locations as another molecule that causes drowsiness called adenosine (see article on coffee, p. 7).

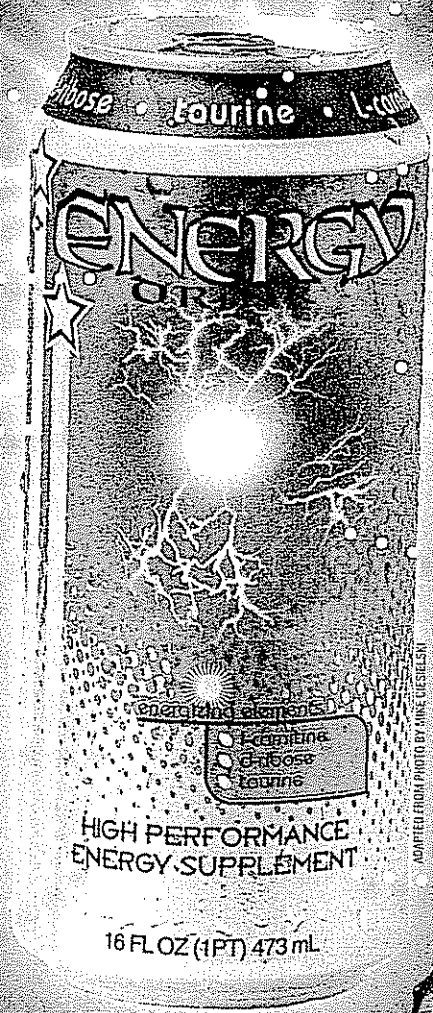
INOSITOL ($C_6H_6(OH)_6$): helps to break down cholesterol and fat in the arteries and liver.

VITAMIN B_6 ($C_8H_{11}NO_3$): involved in the production of hemoglobin—the molecule that carries oxygen in the blood; found in bananas, legumes, chicken, liver, potatoes, milk, and fish.

VITAMIN B_3 (niacin: $C_6H_5NO_2$): helps to release energy from foods and lowers cholesterol; found in milk, eggs, meat, fish, green vegetables, and whole grains.

VITAMIN B_{12} (cobalamin: $C_{63}H_{88}CoN_{14}O_{14}P$): used by the body to make fat, carbohydrates, and proteins; found in animal liver, fish, milk, and meat.

SUCROSE (table sugar: $C_{12}H_{22}O_{11}$): composed of two molecules of simple sugar: glucose and fructose; made by refining either sugar cane or sugar beets.



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TAURINE (2-aminoethanesulfonic acid: $C_2H_7NO_3S$): a staple in most energy drinks; was first isolated from ox bile but is now made synthetically.

CARBONATED WATER (carbon dioxide (CO_2) dissolved in water): the primary ingredient in all carbonated beverages.

GLUCOSE ($C_6H_{12}O_6$): a monosaccharide or simple sugar manufactured by green plants during photosynthesis and stored in plants in the form of starch.

GLUCURONOLACTONE ($C_6H_8O_6$): sugar present in the liver as a result of glucose metabolism; included in energy drinks because it may fight fatigue by acting as a stimulant.

SODIUM CITRATE (also called trisodium citrate: $Na_3C_6H_5O_7$): tastes both sour and salty, usually used to impart a tangy flavor; used to treat urinary tract infections.